TROPICAL AGRICULTURE

THE OFFICIAL JOURNAL OF THE
IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

VOL XXII No. 9 SEPTEMBER, 1945 PRICE 6d

CONTENTS

	PAGE
Colonial Research	157
Natural Humus and Artificial Fertilizers ...	159
The Western Pacific High Commission Territories—Tonga	160
The Effect of Compost on Sugar-Cane Plants affected by Streak Disease	163
Root-rot of Cocoyams (*Xanthosoma sagittifolium*, Schott)	164
Plant Breeding in relation to Human Nutrition	171
Chemical Notes	175

THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE, TRINIDAD, B.W.I.

Cables :: "Stomata." | Phone :: 0365

TROPICAL AGRICULTURE is published monthly at the Imperial College of Tropical Agriculture, St. Augustine, Trinidad, West Indies. Advertisement and Subscription rates can be obtained at the College from the Editor, or from the Secretary of the College, Grand Buildings, Trafalgar Square, London, W.C. 2, England. The Editor will be glad to consider authoritative articles for publication. It is understood that opinions expressed or recommendations made in signed articles or in articles of which the source is named are those of the author and do not necessarily represent the policy or opinion of the College Authorities. Increasing numbers of inquiries are being received from the various parts of the tropics which can be answered only by persons possessed of an intimate knowledge of local conditions. Enquirers should first satisfy themselves that their local Department of Agriculture is not able to supply them with the desired information before communicating with us. Correspondence which will be replied to is invited on all other matters pertaining to tropical agriculture, science and development.

COLONIAL RESEARCH *

IN the Colonial Development and Welfare Act of 1940 there was included provision for the expenditure in any one year on "research and investigation" of such sums, not exceeding £500,000, as Parliament might approve. This provision, half as much as the entire provision for Colonial development from United Kingdom funds under the Colonial Development Act of 1929, was an expression of a sense of the need for more knowledge, and new knowledge, if the whole policy of development and welfare in the Colonies is to be successful. It has proved, moreover, to be a stimulus to still greater interest in the part which science can play in the development of the Colonies as well as of Great Britain itself.

An immediate consequence was that the Secretary of State felt it necessary to create an organisation to advise him on the most effective means of applying these new resources. This organisation is the Colonial Research Committee, set up in 1942, under the Chairmanship of Lord Hailey. The membership of the Committee is as follows:—

Sir Edward Appleton (Secretary, Department of Scientific and Industrial Research), Mr. A. M. Carr-Saunders (Director of the London School of Economics), Mr. J. C. F. Fryer (Secretary of the Agricultural Research Council), Brig.-General Sir Harold Hartley, Professor A. V. Hill, M.P. (Secretary of the Royal Society), Sir Edward Mellanby (Secretary of the Medical Research Council), Professor Arnold Plant (Sir Ernest Cassel, Professor of Commerce in the University of London), and Dr. Audrey Richards (Lecturer in anthropology in charge of Colonial Studies, London School of Economics).

It will be seen that by this membership full liaison is assured with the three great Governmental research organisations in Great Britain, and also, through the Royal Society, with the world of natural science generally. No comparable link is as yet possible as regards the social sciences, since there does not yet exist in this country any organisation which performs in respect of those sciences the functions performed for medical research, for example, by the Medical Research Council.

* Abstracted from an article "Colonial Research" by C. Y. Carstairs in *African Affairs*, Vol. 44, 1945.

In practice, the work of the Committee falls into two categories; the scrutiny of individual research schemes originating in the Colonies or otherwise and involving finance under the 1940 Act; and the systematic review of existing arrangements for research, in order to ascertain where the gaps are, and to make recommendations as to the best means of filling them. War conditions, which have imposed heavy burdens of urgent work on depleted Colonial administrations, have naturally reduced the flow of schemes which might otherwise have been expected; and a still more serious obstacle to rapid progress is the acute shortage of trained scientists to carry out the research work itself. Some progress has nevertheless been possible. Up to the end of March, 1944, schemes had been sanctioned estimated to cost in all some £240,000, and the pace is increasing. But partly as a result of this inescapable hold-up in the planning and execution of definite projects, the Committee has been able to concentrate its attention on review, and on questions of organisation.

As a first step, the Committee called for studies of the existing provisions for research in the following fields:—(1) The Social Sciences, (2) Agriculture (with animal health and forestry), (3) Medicine and public health, (4) Geodetic and topographical survey, (5) Geological survey.

The results of these studies led the Committee to make certain recommendations regarding organisation. As regards the first three topics, they came to the conclusion that there was a need for separate *ad hoc* advisory bodies to deal with research in these particular fields. Separate, because each of the fields is sufficiently wide to require the attention of a number of specialists, and because the planning of research is a task sufficiently specialised and distinct to warrant its separation from bodies dealing primarily with administration and policy. *Ad hoc*, because any single body qualified to plan and steer research in all these fields would be far too large and unwieldy for practical efficiency. In the event, there has already been established a Colonial Social Science Research Council under the Chairmanship of Mr. Carr-Saunders; and approval has been given for the establishment of a Colonial Medical Research Committee. The proposal for a Committee to deal similarly with research in agriculture, animal health and forestry is still under consideration.

The other two subjects, namely mapping and geological surveys, fall into rather a different class. They do not involve research in the narrower sense of the term, but they are in fact fundamental to the sound, efficient and economical development of any territory, as well as to the selection of problems and localities for research of the more fundamental type. Much survey and geological work has, of course, already been done in many territories, whether by Governments or, in some cases, by private enterprise, notably mining companies. But vast areas remain unmapped or inadequately mapped, and geologically explored superficially if at all. Survey and geological work has in fact suffered from certain peculiar disabilities. It is, at first sight, expensive in relation to any obvious and immediate return, and has therefore appeared to be outside the means of the less prosperous territories, who might nevertheless stand in at least as great need of good survey work as many more fortunately placed. Further, survey work is undramatic, being carried out largely in remote areas by small and inconspicuous parties of nomadic specialists. Its value may be slow in manifesting itself, or emerge so indirectly as not to be readily recognisable or to be taken for granted. The result has been that survey work has been peculiarly prone to interruption in times of financial stress. Once it has been laid aside, it may not be easy for Colonial legislatures or Governments, besieged by the claims of projects of more obvious or immediate value, to bring themselves to resume it. A third important factor, particularly as regards mapping, is that political and administrative frontiers are irrelevant to its proper execution. The basic need is an accurate major geodetic triangulation, upon which the accuracy of topographical mapping and of the end product of detailed cadastral mapping wholly depends. Thus it may happen that work essential for the accurate mapping of a given territory may require to be done far outside its own borders.

As to the vital need for this work there can be no doubt. Inadequate topographical mapping renders progressively more difficult the task of Lands Departments as a territory becomes more densely settled and the accurate delimitation of landholdings a matter of increasing importance. An accurate knowledge of the configuration of the land is essential to avoid the risk of great waste of money and effort in certain major public works. In one case, for example, an entire railway line has had to be lifted, realigned and relaid, at a cost of millions of pounds, because the original plan had been based on inaccurate topographical information. Accurate meteorological information, which is needed both for agriculture and for the safety of air transport, is scarcely possible without accurate knowledge of the position and height of the various points of observation. Sound topographical data, moreover, are essential for comprehensive (as distinct from patchwork) geological survey and mapping; and this in turn is essential, not only for the systematic exploitation of a territory's mineral resources, but for the classification of its soil and the mapping of underground water supplies—a matter of great moment in many parts of Africa and elsewhere.

The need for a new policy in regard to these matters had already been appreciated by the Colonial Office Survey and Geophysical Committee and by the scientific bodies in this country concerned with geology; and the Colonial Research Committee does not claim to have inspired the formulation of new and comprehensive plans for the re-organisation of these

two branches of work in the Colonial Empire. Their intervention was however valuable and came at a crucial moment. As a result, the Secretary of State instructed the Survey and Geophysical Committee to appoint a Sub-Committee to frame recommendations regarding geodetic and topographical survey. At the same time he invited a number of leading experts to join with members of the Colonial Office in a Committee to frame proposals regarding geology. Both these bodies have now submitted their reports and they have been forwarded to the Secretary of State with the hearty support of the Colonial Research Committee. The central proposal is in the first case the creation of a central organisation for all geodetic and topographical survey in the Colonial Empire. The plans envisage the completion of the major triangulation of the Colonies within a period of ten years, together with the topographical mapping of half the total area, with the aid of all the latest techniques, including air photography. In the case of geology the proposal is that in the principal regions of the Colonial Empire (the West Indies, West Africa, etc.) the work should be organised on a regional basis and that a central team based on London should be responsible for the isolated dependencies.

Another major problem to which the Colonial Research Committee has given attention has been the terms of service of research workers in the Colonies. Some work on Colonial problems, notably much of that sponsored by the Colonial Products Research Council, can best be done in this country, or in some other place outside the Colonies themselves. But by far the most research work will necessarily continue to be carried out in the Colonies; and here special problems arise. For the Colonial administrative and most of the technical services, the terms of service are based on the assumption that they constitute a lifelong career, and rightly so. In the case of many if not all research workers, however, it is even more important that they should remain in close touch with the main stream of development in their particular sciences, if they are not to lose their value. For this reason, it has often happened in the past that scientists have been reluctant to take up posts in the Colonies, for fear of being committed to a lifetime away from the main sources of scientific progress, and of endangering their own chances of advancement in their own profession. To meet this difficulty the Committee has recommended that research workers, instead of being engaged in a pensionable capacity, should be engaged on terms comparable to those embodied in the Federated Superannuation Scheme for the Universities. Under this scheme each worker holds an insurance policy entitling him to an annuity when he reaches a cetain age or his heirs to a lump sum if he dies before that age. His employer for the time being pays a fixed proportion (normally two-thirds) of the annual premium and, as his salary increases, supplementary policies are taken out which increase the benefits on retirement or death. Under this system the worker can move freely from governmental to non-governmental employment or vice versa, taking his insurance policy with him, and his employer for the time being pays the fixed proportion of the current premium. He can even, if he wishes, retire into private life and either obtain the surrender value of the policy or keep up the payments until the annuity falls due. The creation of special research services, which is what this recommendation would involve, has the further advantage that it would tend to inhibit the employment of skilled research workers on routine anlayses and other duties on which their special qualifications and aptitudes are at present sometimes wasted. If such separate services are created, it will obviously be necessary to take particular care to ensure that there is the closest liaison between those who seek for new knowledge and those whose duty it is to apply it. This again is a question of organisation of some complexity and importance, and it is scarcely possible now to say more than that it is receiving much attention.

NATURAL HUMUS AND ARTIFICIAL FERTILIZERS

R. H. Folett-Smith, in *Proceedings British West Indian Sugar Technologists*, 1943, pp. 21-25, takes notice of recent writings by Sir Albert Howard, a British agriculturist, who says that most of the agricultural and economic difficulties experienced in the West Indies are due to the substitution of organic manures by artificial fertilizers. Against this, it is pointed out, first, that it would be difficult to find a considerable sugar cane area where so little has been done in the past 40 years to augment the organic matter content of the soil as in British Guiana. At the beginning of the present century it was the general practice in this colony to bury the cane trash. About that time labour difficulties made it necessary to burn the cane before cutting, and it was found that commercial fertilizers were superior to organic manures as a source of nitrogen. Since then the commercial fertilizers have been the sole fertilizing material. It is then pointed out that in 1903 the yield was approximately 1.6 tons of sugar per acre, and by 1938 it averaged over 3 tons. A study of the results obtained during the period 1926-39 when unrestricted supplies of artificial fertilizers were available, shows a very definite correlation between the rate of application of ammonium sulphate and the production of sugar in the colony. The correlation coefficient between these two is + 0.917.—(*Sugar*, Vol. 40, No. 6. p. 54, 1945.)

The Editor requests that any subscriber who fails to receive *Tropical Agriculture* regularly should communicate with him immediately in order that the matter may be rectified.

THE WESTERN PACIFIC HIGH COMMISSION TERRITORIES

The Western Pacific High Commission, Territories consist of: 1. the Kingdom of Tonga, a constitutional monarchy under British protection, 2. the British Soloman Islands Protectorate, 3. the Gilbert and Ellice Islands Colony, and 4. the Anglo-French Condominium of the New Hebrides (*See* Map 1.) These Territories are under the jurisdiction, complete or in part, of the Imperial Government, exercised through the Colonial Office, and are administered by the High Commissioner for the Western Pacific who is also Governor of Fiji. The series of articles commenced in this issue of *Tropical Agriculture* consist mainly of extracts from the descriptive sections of a "Report on Agricultural Policy for Fiji and the Western Pacific High Commission Territories" prepared by Professor C. Y. Shephard at the request of the High Commissioner. Reference should be made to the original report for Professor Shephard's recommendations concerning agricultural policy.

C. Y. S.

TONGA

BY

C. Y. SHEPHARD

(Carnegie Professor of Economics, Imperial College of Tropical Agriculture)

Geography. The Kingdom of Tonga lies between 15 degrees and 23 degrees south latitude, and 173 degrees and 177 degrees west latitude, and consists of three main groups of islands, namely, (i) Tongatabu in the south; (ii) Ha'abai in the centre, and (iii) Vava'u in the north. Ha'abai is an extensive archipelago of very small islands but the Tongatabu and Vava'u Groups consist of one large island and several small adjacent islands. There are more than 150 islands in the Tongan Group but most of them are very small and only 36 are inhabited. The total area is 269 square miles and the population, 33,000. The Tongan islands run north and south in two parallel chains, the western, volcanic, and the eastern, coralline. The volcanic islands descend steeply into the sea but the coral islands have barrier reefs around them. Nuku'alofa, on Tongatabu, is the capital of the Kingdom and the centre of trade for the whole Group. Nuku'alofa is 2,000 miles from Sydney, 1,100 miles from Auckland and 430 miles from Suva.

Table 1

Area and Population

Group	Area (sq. miles)	Population
(i) Tongatabu, 'Eua, etc.	136	15,211
(ii) Ha'abai ...	50	7,180
(iii) Vava'u ...	83	10,470
Totals	269	32,861

Rainfall. The average annual rainfall ranges from 63 inches in the south to 106 inches in the north. The wet season extends from the end of December to April. Short but injurious droughts are sometimes experienced, more especially during the period October-December.

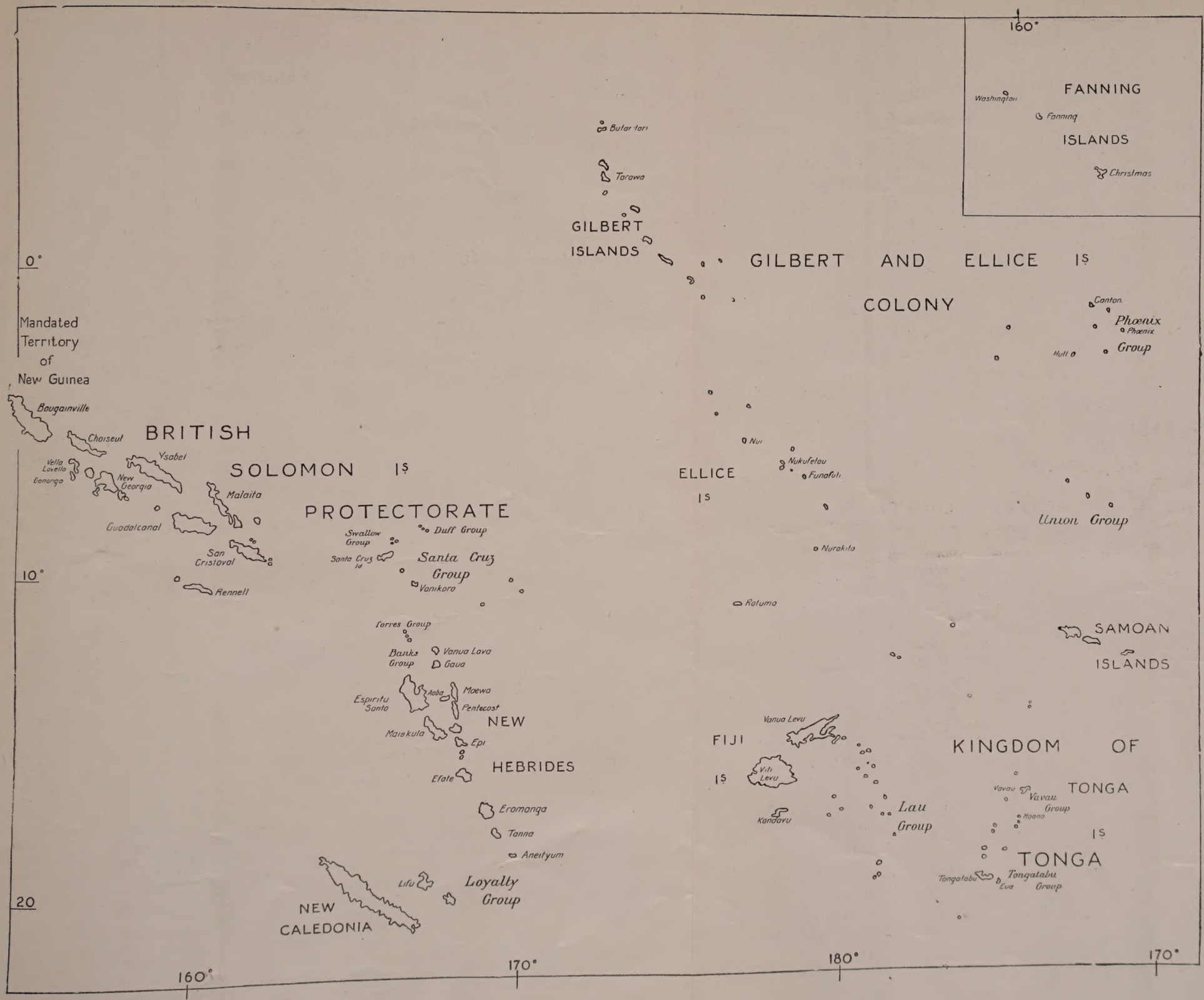
History. Four independent native States in the Pacific—Fiji, Hawaii, Samoa and Tonga—gained international recognition during the 19th century, but three eventually succumbed. Tonga owes its survival as a Kingdom mainly to the long and enlightened rule of King George I, a Polynesian warrior and administrator of outstanding ability.

Early European navigators had found the Tongans a most industrious, orderly and peaceable people. Cook named the Group the Friendly Islands. The peaceful condition observed by Cook soon gave way to bitter internal strife which persisted well into the 19th century until the head of the Tubou family established sway over the entire Group and was crowned King of Tonga in 1845. The King had adopted Christianity in 1831 and had taken the name George at his baptism.

In 1862 King George emancipated the people from the semi-serfdom under which they had laboured for centuries, voluntarily limited his own powers as sovereign and established a Parliament with a Privy Council and Cabinet. King George gained the respect of the representatives of European nations in the Pacific to a remarkable degree and by the time of his death in 1893 at the age of 96 the foundations of the present constitution had become firmly established.

Constitution. The present Government consists of, (i) the Sovereign (Queen Salote) and the Privy Council, (ii) the Cabinet, and (iii) the Parliament or Legislative Assembly. The members of the Privy Council consist of the Sovereign, the Speaker, the Premier, the Ministers of Lands and Police, the Governors of Vava'u and Ha'abai and two European members, namely, the Chief Justice and the Treasurer. The Privy Council advises the Sovereign on affairs of State, makes ordinances in the intervals between Parliaments and prepares the annual Estimates of Revenue and Expenditure for submission to the British Consul and Parliament.

The Cabinet consists of the members of the Privy Council, except the Sovereign and the Speaker. The Cabinet controls the property of Government, makes appointments to the Public Service and determines such matters as the terms on which land may be leased.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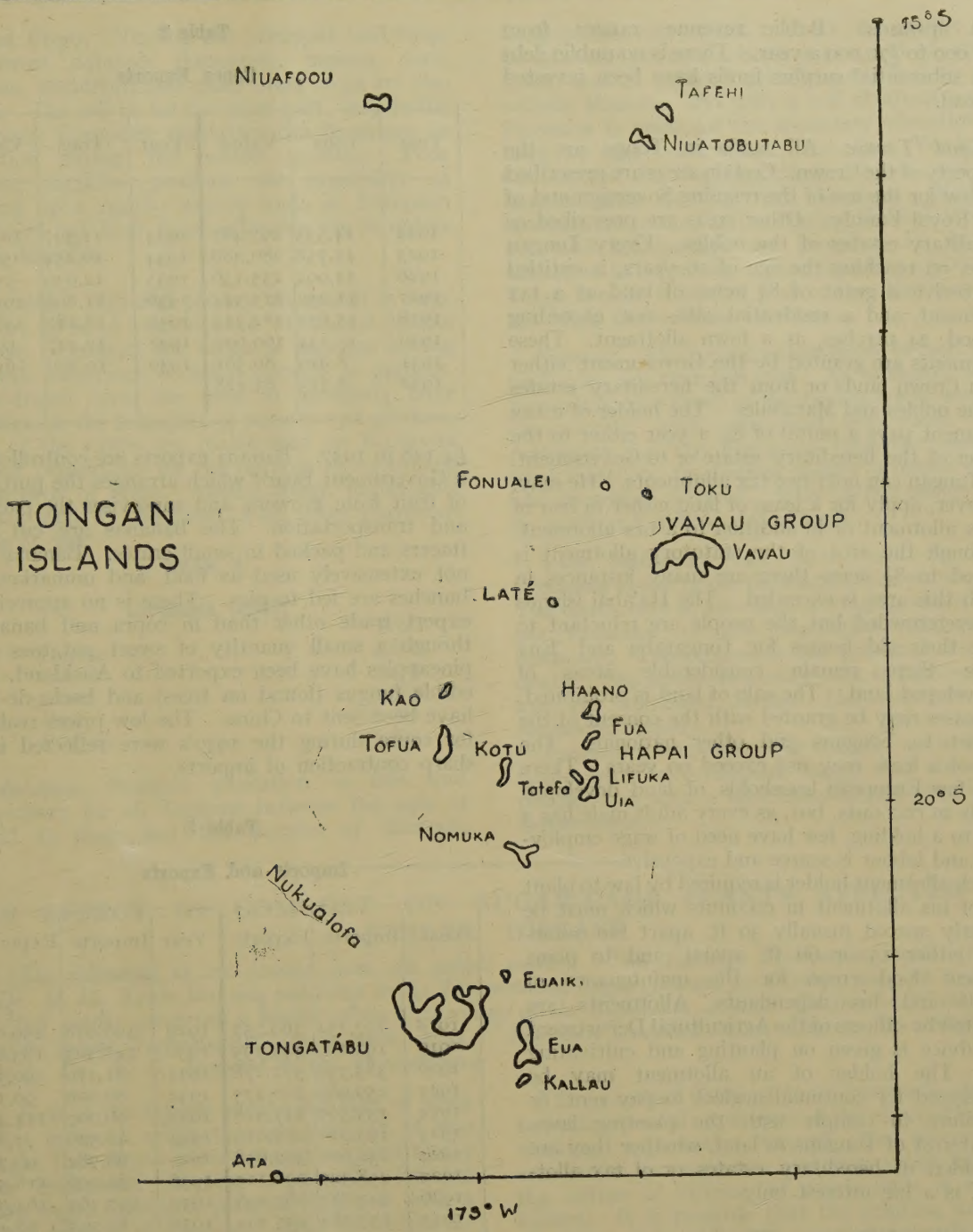

Parliament is composed of the Speaker and members of the Cabinet, seven nobles elected by the thirty-three nobles of the Kingdom and seven representatives elected by male taxpayers 21 years and over. The three sections of Parliament sit at different tables in the House but their votes are recorded together. Elections are held triennially. The House sits for about four weeks each year.

The Kingdom of Tonga became allied to Great Britain by the Treaty of Friendship and Protection of 1901. The British Agent and Consul can veto expenditure and must approve the appointment of all Europeans in the Tongan Government. He advises on all external affairs, and also on internal matters if requested to do so by Government. Thus, except for the supervisory powers exercised by the Consul, the Tongans administer their own affairs. The people are Tongan, and not British, subjects and the Kingdom has its own postage stamps and currency notes.

Public Finance. Customs receipts from import and export duties provide nearly half the public revenue. There is an export duty on copra of £1 per ton. The chief direct tax is a poll tax of 36/- per annum on all Tongan males of sixteen years

and upwards. Public revenue ranges from £60,000 to £70,000 a year. There is no public debt and substantial surplus funds have been invested abroad.

Land Tenure. All lands in Tonga are the property of the Crown. Certain areas are prescribed by law for the use of the reigning Sovereign and of the Royal Family. Other areas are prescribed as hereditary estates of the nobles. Every Tongan male, on reaching the age of 16 years, is entitled to receive a grant of 8¼ acres of land as a tax allotment, and a residential site, not exceeding 1 rood, 24 perches, as a town allotment. These allotments are granted by the Government either from Crown lands or from the hereditary estates of the nobles and Matabules. The holder of a tax allotment pays a rental of 8*s*. a year either to the holder of the hereditary estate or to Government. No Tongan can hold two tax allotments. He may, however, apply for a lease of land either in lieu of a tax allotment or in addition to a tax allotment. Although the area of the statutory allotment is limited to 8¼ acres there are many instances in which this area is exceeded. The Ha'abai islands are overcrowded but the people are reluctant to leave their old homes for Tongatabu and 'Eua where there remain considerable areas of undeveloped land. The sale of land is prohibited, but leases may be granted with the consent of the Cabinet to Tongans and other nationals. The term of a lease may not exceed 99 years. There are a few European leaseholds of land developed mainly in coconuts, but, as every adult male has a right to a holding, few have need of wage employment and labour is scarce and expensive.

Each allotment holder is required by law to plant half of his allotment in coconuts which must be regularly spaced (usually 30 ft. apart but sometimes either 15 or 60 ft. apart), and to plant sufficient food crops for the maintenance of himself and his dependants. Allotments are inspected by officers of the Agricultural Department and advice is given on planting and cultivating crops. The holder of an allotment may be dispossessed for continual neglect to pay rent, or for failure to comply with the planting laws. The interest of Tongans in land, whether they are the holders of hereditary estates or of tax allotments, is a life interest only.

Agricultural Practice. The Tongans practise a system of bush fallowing. A portion of the land is cultivated in mixed crops for one or two years and then allowed to revert to bush for the next three or five years after which it is burnt over and then brought into cultivation again. Coconuts are used extensively for cooking and drinking purposes and for feeding to pigs and fowls.

Exports. Copra is the principal export. The export of copra is controlled by a Government Board whose agents purchase copra, according to grade, from the producers. Bananas are exported to New Zealand under a quota system. Exports of bananas were valued at £7,373 in 1936 and at £4,128 in 1937. Banana exports are controlled by a Government Board which arranges the purchase of fruit from growers, and supervises the packing and transportation. The bananas are cut into fingers and packed in small crates. Bananas are not extensively used as food, and unmarketable bunches are fed to pigs. There is no appreciable export trade other than in copra and bananas, though a small quantity of sweet potatoes and pineapples have been exported to Auckland, and edible fungus (found on trees) and beche-de-mer have been sent to China. The low prices realised for copra during the 1930's were reflected in a sharp contraction of imports.

Table 2

Copra Exports

Year	Tons	Value	Year	Tons	Value
		£			£
1924	14,533	297,487	1933	11,397	105,028
1925	13,758	280,386	1934	10,154	59,941
1926	13,992	255,156	1935	12,039	79,003
1927	11,252	225,344	1936	11,899	105,078
1928	15,671	282,344	1937	12,287	158,133
1930	14,134	169,609	1938	12,427	90,398
1931	8,929	80,361	1939	10,500	64,545
1932	8,323	83,228			

Table 3

Imports and Exports

Year	Imports	Exports	Year	Imports	Exports
	£	£		£	£
1918	177,151	169,757	1929	198,078	259,090
1919	193,169	443,195	1930	148,305	183,204
1920	383,759	372,278	1931	81,170	90,596
1921	259,969	206,275	1932	86,006	96,163
1922	133,393	217,518	1933	86,007	114,447
1923	195,020	267,619	1934	48,526	77,842
1924	232,600	306,658	1935	68,782	90,711
1925	258,322	290,115	1936	92,296	116,539
1926	227,882	263,198	1937	137,365	164,620
1927	157,783	235,391	1938	82,795	98,463
1928	211,907	287,668			

Imports. Imports into the Colony during recent years are shown in Table 3, the chief imports consisting of drapery (£A.28,000), meats (mostly tinned) (£A.20,000), flour (£A.11,000), bags (copra sacks) (£A.7,000), hardware (£A.6,000), motor cars and accessories (£A.5,000), timber (£A.4,000), sugar (£A.4,000), petrol (£A.4,000), kerosene (£A.3,000), galvanized iron and manufactures (£A.3,000), biscuits (£A.3,000), machinery, (£A.2,000), rope (£A.1,000). The chief countries from which goods are imported are New Zealand and Australia.

Food Crops. Yam is the principal food crop, but sweet potatoes (kumaras), tapioca, taro, plantain, breadfruit and many other crops are also grown. The soil is, for the most part, very fertile and many European vegetables can be grown to perfection during the winter months. Poor shipping facilities preclude the possibility of building up a regular export trade in European vegetables but their more extensive use in native diet is desirable.

Livestock. Pigs and poultry are reared in large numbers for local consumption. Pens and ditches are used to restrict the range of pigs but roving pigs still sometimes occasion damage to gardens. Horse-drawn carts are used in unusually large numbers for the transport of persons and produce. Most of the cattle are maintained on European coconut plantations for the purpose of controlling the growth of grass. Animal-drawn implements are not used by Tongans. Fish is an important article of diet.

Table 4

Livestock (1937)

	Nos.
Horses	4,866
Cattle	2,478
Goats	3,583
Pigs	18,060
Poultry	48,302

Education. Primary education is free and compulsory for all Tongans between the ages of 6 and 14 years and the number of illiterate Tongans is very small. There are about 70 Government primary schools with a roll of about 3,000, and 40 primary schools controlled by the various Missions, also with a roll of about 3,000. Provision is made for the secondary education of boys by the Government, the Free Wesleyan Church and the Roman Catholic Church, and for that of girls by the two Missions. Medical students are trained at the Central Medical School, Fiji and scholarships are provided for higher education in Australia. The education system in Tonga is more advanced than in the other parts of the High Commission Territories.

Housing. The typical native house is built with reed sides and thatched roof. An unusually large proportion (one-third) of the houses are of wooden construction, with corrugated iron roofs. The preference for the European type of house is accentuated by the limited supply of native wood and thatching material. Most of the people live in small and well tended villages.

Vital Statistics. The birth rate is high, averaging about 37 per thousand of the population. The death rate is also high averaging about 17.5 per thousand of the population. Malaria is unknown. Tuberculosis is the principal cause of death. The infant mortality rate is high—about 119 per thousand births. The population is increasing steadily.

Tongatabu impresses the visitor as a fertile island with an intelligent, happy and contented people, and with a well ordered and progressive Government.

THE EFFECT OF COMPOST ON SUGAR-CANE PLANTS AFFECTED BY STREAK DISEASE

(The following is an extract from an article entitled "Soil Fertility Problems in South Africa" by Dr. H. M. Leake that was published in the International Sugar Journal for October, 1944, pp. 259-261. The full article comprises a review of the Proceedings of the Eighteenth Annual Conference of the South African Sugar Technologists' Association, 1944. The part extracted below describes a contribution made by Dr. G. C. Dymond to the Proceedings.)

In view of the reports noting the cure of virus disease in truck crops through compost, it was thought that streak disease might respond to the same treatment. A few moderately infected plants were, therefore, planted in a row with a normal dressing of compost. After two years the degree of infection remained the same at 60 per cent, while in the control from the same seed infection had increased to 100 per cent. The plants were then, after the second cutting, surface-dressed with compost and, by the end of the third year, infection had diminished to 25 per cent. During the fourth year the crop was passed as entirely free from infection. All this cane was then planted out in a composted bed and a line of cane with 100 per cent. infection planted adjacent to it. After six months, the former has remained free from infection. Investigation of the mycorrhizal association showed absence of mycorrhiza in the roots of diseased cane but presence in the healthy cane.

The practical value of these results is obvious but this repeated experience of the effect of humus, working apparently through the mycorrhizal association, is suggestive and may throw light on the nature of viruses, of which little is as yet known. It is possible that the solution may lie in some modification of the protein molecule under unbalanced conditions of nutrition and that infection follows the injection by the vector of such altered molecules into the healthy plant, with a result comparable to the effect of introducing a crystal into a super-saturated solution. If that be the case, viruses would be the products of the plant itself and the remedy must be sought through a better understanding of the nutritional balance and not through the usual channels for meeting parasitism. The present and similar observations, therefore, had a wider significance than that of their direct practical application to economic problems.

ROOT-ROT OF COCOYAMS (*XANTHOSOMA SAGITTIFOLIUM* SCHOTT)

BY

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Introduction

THE purpose of this paper is to record the results of a number of experiments done by the writer since 1940, and to correlate the findings with those of previous investigators of this abstruse problem. It must be admitted that these recent experiments have contributed little towards the control of the disease, but possibly they may help to clarify the situation for future investigators by providing evidence for a plausible working hypothesis.

The history and symptoms of the disease have been described by Wright (4), whose paper gives a full account of investigations leading to the conclusion "that all the organisms (associated with diseased plants) including this species of *Pythium*†, are soil saprophytes and only become capable of attacking the roots when the plant is in a debilitated state and the roots have already begun to die off. The most probable reason for this condition is a deficiency in available potash".

Subsequent work by Dade and Wright has been reviewed by Shepherd (3), who records the gradual spread of the disease through the Gold Coast, the failure of ordinary nutrient deficiencies and reaction of the soil to affect the disease, the toxicity of an agent obtained from rotting roots, and the failure of fungicides and cultural operations to control the disease in the field.

Between 1938 and 1940 Shepherd investigated the problem, and in addition to confirming the findings of Dade and Wright he showed that sulphur and borax applied to the soil do not prevent root-rot.

When the writer took over these investigations from Shepherd in 1940, the following points were regarded as of primary significance :—

1. The history of the disease, as recorded by Wright (*loc. cit.*) and in unpublished reports, showed a comparatively recent origin and a gradual spread from sporadic outbreaks in widely separated localities on the Gold Coast. Since 1930, the disease has appeared near Axim and spread northwards in the Enchi district (1932) 30 miles in three or four years. In 1933, it was reported in the Kumasi district, in 1936, near Wiawso in the Western Province and in 1939, in Togoland. A visit to Wiawso in 1942 revealed that the disease was far less prevalent there than formerly and seemed to be disappearing.
2. In 1940, it was reported that a farmer in the Bekwai district of Ashanti avoided the disease by rogueing all cocoyams found on the land after clearing the bush, and replanting with material obtained from an area where root-rot did not occur.
3. The "toxin" of earlier workers was present in filtered extracts of "sick soil" and roots, was effective in small quantities, and was destroyed by heat-sterilisation.

These facts strongly suggest the presence of a virus, with properties like those of the tobacco necrosis virus, which infects the roots of tobacco plants grown in contaminated soil, although the tops remain free from virus (1). Tobacco mosaic can also be contracted by plants growing in infected soil. The outstanding fact recorded by previous workers which argues against virus is the recovery of affected plants when growing in "garden compost" (Shepherd *loc. cit.*). Experiments described later show that this recovery does not always occur and may not be permanent. It is explainable on the assumption (suggested by all previous workers) that two factors are responsible for the full expression of root-rot symptoms, and that these are a virus which weakens the plant and a weak parasite, fungal or nematode, which then attacks the roots.

The frequent occurrence in undisturbed bush of healthy cocoyams which succumb to root-rot when cultivated, is not a serious argument against a virus being the pathogen. The disease can be spread by the movement of "Sick soil," as would occur in cultural operations, and if a virus, by insect vectors, which may not attack plants in "bush." Such "bush" always contains, besides these cocoyams growing well, many dormant corms which are stimulated by clearing, and these legacies from a previous farm may form the source from which the disease spreads.

Some of the experiments to be described were designed to show whether a virus as the causal agent would form a workable hypothesis; other experiments are frankly empirical. It must be emphasised that this investigation touches only the fringe of the problem, and it is regretted that it was not possible to carry out many critical experiments suggested by the work of Johnson (2) on Brown Root-rot of Tobacco, a disease with many features in common with cocoyam root-rot.

The present investigation was done at the Central Cacao Research Station, and was always secondary to cacao problems.

Field Experiments

The object of these experiments was to find a means of reducing the incidence and severity of the disease in the field, and thereby to obtain more information about the pathogen responsible. All methods which had shown any promise in earlier investigations and suggestions of farmers were tried. These were :—

1. The application of potash in the form of wood ash.

† Later identified as new species near *Pythium gracile* Shenk.

2. Burning compared with leaving the cut "bush" to rot after clearing.
3. Deep forking before planting, compared with the surface cultivation usually practised.
4. Interplanting with a leguminous cover-crop.
5. Using light shade provided by thinning the "bush" without any soil disturbance.
6. Rogueing all "wild" cocoyams before replanting with setts from an area where the disease does not occur.

Only the last two methods reduced the incidence of the disease, but their effect lasted for only one year.

Layout of Experiments

From previous observations on the disease it was thought probable that the effect of any treatment in delaying root-rot on small plots would be soon lost by the spread of the disease from adjacent plots. Since the total area of experiments was limited it was decided that more information would be gained by using a few large plots than many small ones, despite the loss in statistical accuracy.

1. Burning and Leguminous Cover Effects

Half an acre of land, known to have been contaminated with root-rot some ten years before, was cleared in May, 1941, and divided up into eight plots. On alternate plots the bush was burnt; on the other four it was allowed to rot. Each plot was then split, and *Crotalaria retusa* planted as a leguminous cover on half. This cover did not become well established until after the disease had appeared. A uniform stand of cocoyams was obtained by thinning where the natural regeneration was too thick and by interplanting where it was sparse.

As shown in Table 1, the disease started in July, small patches of two to six plants wilting in each plot. By the end of December only a few healthy plants remained on the whole experiment. The disease spread by the formation of small scattered outbreaks, each of which gradually enlarged until they merged. Table 2 shows no significant difference between the yields obtained from these treatments.

Conclusions

The presence of a legume planted while the cocoyams are sprouting has no retarding action on root-rot.

It makes no difference whether the "bush" is burnt or allowed to rot on the land.

2. Rogueing, Forking and Wood Ash

This experiment was run concurrently with that just described, and the size and layout are identical, except that half the plots were deep-forked before planting. Land was cleared in May, 1941, the "bush" burnt according to African practice, and two strips deep-forked. All the "wild" plants were carefully dug up and removed from four plots, which were then replanted with setts obtained from Begoro, where root-rot does not occur. The remaining four plots were treated in the local manner, the regenerating plants which had been dormant in the "bush" were thinned or interplanted, according to their density. The plots were then split, and half of each was covered with a thin layer of wood-ash (to supply additional potash). Outbreaks of root-rot started in July, and weekly records were kept, their occurrence and spread being mapped. Table 3 indicates the delaying action of the Rogueing and Replanting method, but does not adequately record the striking difference between the rogued and inter-planted plots. There were a few spontaneous outbreaks in the rogued plots, but most of the damage was done at the edge of these plots, apparently by the disease spreading from adjacent outbreaks on unrogued plots.

TABLE 1

Monthly Distribution of Outbreaks on Experiment 1

Treatment	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Burnt	29	24	19	5	10	1	88
Not Burnt	11	34	18	7	11	3	84
Cover Crop	21	26	14	8	9	2	80
No Cover	19	32	23	4	12	2	92

TABLE 2

Yields per Plot in Pounds from Experiment 1

										Total
Burnt	154	139	81	151	92	82	41	50		790
Not burnt	151	150	128	109	52	51	43	32		716
Cover Crop	305	—	209	—	144	—	84	—		742
No Cover	—	289	—	260	—	133	—	82		764

Neither forking not wood-ash had any obvious effect on the disease, although the forked plots gave a higher yield when the cormels were harvested in April, 1942.

In May, 1942, the experiment was replanted, on the same land. Each plot receiving setts from the plants which had grown on it during the previous year. The disease appeared in the same distribution as at the end of the previous year and spread rapidly into the remaining healthy patches on the rogued plots. By September, 1942, the whole area was affected with root-rot, and no marketable corms were harvested when the experiment was concluded in May, 1943.

Conclusions

Neither forking to improve the tilth before planting, nor the application of wood-ash reduced the incidence of root-rot.

When no rogueing is done prior to planting, introduced healthy setts soon succumb, but rogueing of all cocoyam plants and dormant corms before planting with fresh setts from a disease-free area delayed and reduced the incidence of the disease, though only for one season.

3. Rogueing, Source of Setts, and Shade

The experiment last described suggested that the removal of dormant corms was the essential part of the control, but another possible explanation was that the "Clean" setts obtained from Begoro were more resistant or more vigorous than the local type. In May, 1942, an experiment was started, designed to decide this issue and also to test the possibility of avoiding the disease by controlling the "bush" growth to give only light shade, leaving the soil undisturbed.

From the experience gained in earlier experiments, it was considered advisable to use larger plots and to leave paths 6 ft. wide between the plots to reduce the "edge effect."

Before clearing, traces were cut through the bush to demarcate eight one-eighth acre plots. Treatments were allocated as shown in Table 5, and the bush on all but two plots cleared and burnt. On the two remaining plots the "bush" was cutlassed at a height of 3 feet from the ground; on these two and on two other plots, the "wild" cocoyams were allowed to grow, being interplanted with setts from the same disease-free area at Begoro. On four other plots, all "wild" cocoyams, including dormant corms, were carefully removed, and then two plots planted with Begoro setts, and two with setts from a plot of young cacao at Tafo on which there was no sign of root-rot.

Table 4 shows that root-rot appeared on the unrogued four months earlier than on the rogued plots. Again there was a striking difference in the appearance of the rogued and unrogued plots, but little difference between the rogued plots with Begoro and those with Tafo "clean" setts. The spread of the disease from outbreaks in adjacent plots was still apparent although reduced by the 6 ft. paths separating the plots.

The "bush-shade" plots, on which the "bush" was kept cutlassed at about 3 ft. high, allowing the cocoyams to grow vigorously without any soil disturbance, gave conflicting results. One plot was almost entirely free, while the other was attacked severely, though not so heavily as the cultivated unrogued plots. Table 5 shows that this treatment yielded a satisfactory weight of cormels, although they were small.

Conclusions

The success of the Rogueing and Replanting method depends on the removal of "wild" cocoyams, not on the introduction of resistant or more vigorous plants.

An alternative method of avoiding root-rot is to control the "bush" sufficiently to allow "wild" cocoyams to develop, but leaving the soil undisturbed. However this experiment showed that plants growing in "bush" are attacked by the disease, which is contrary to earlier observations.

4. Relative Effects of Soil and Plant Infection

This experiment was laid down in April, 1943, by which time pot experiments (described below) had shown that infected plants can carry the disease with them when transplanted to disease-free soil.

At the end of Experiment 3, the distribution of root-rot on the experimental area was known and recorded on a plan. Some plots were heavily infected and some practically free from the disease. This land was used to find out (*a*) if rogueing has any controlling effect in an active outbreak (as opposed to the latent infection in "bush"); (*b*) if diseased plants would carry the disease with them when planted in previously uninfected soil.

When Experiment 3 was harvested in April, 1943, the cocoyams on each plot were grouped into healthy and diseased lots; the former were

TABLE 3

Monthly Distribution of Outbreaks on Experiment 2

Treatment	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Rogued	—	8	9	9	19	11	56
Not Rogued	6	35	19	5	17	3	85
Wood-Ash	3	23	17	6	16	7	72
No Ash	3	20	11	8	20	7	69

TABLE 4

Monthly Distribution of Outbreaks on Experiment 3

Treatment	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Rogued and Begoro setts ..	—	—	—	—	—	3	3	6
Rogued and Tafo Setts ..	—	—	—	—	1	6	1	8
Bush Shade	2	1	2	—	—	2	—	7
Not Rogued and Begoro Setts ..	3	9	8	—	1	8	—	29

TABLE 5

Yield per Plot in Pounds from Experiment 3

Treatment	Rogued and Begoro Setts	Rogued and Tafo Setts	Bush Shade	Not Rogued & Begoro Setts
Plot	129	58	121	32
Yield	56	73	46	82
Total	185	131	167	114

planted on the plots in which root-rot had been prevalent in the previous season, and the diseased plants were planted on the plots almost free from the disease.

Table 6 shows that plots 1 and 7, which were heavily infected the previous season, showed most outbreaks in June when the symptoms first appeared, and plot 2, also heavily infected before, showed most root-rot in July. As shown in Table 7, there is a positive correlation between the infection in the 1943-44 season and that in the previous year. This conclusively proves that plants can be infected from the soil. However, a comparison of the distribution of root-rot in the two years' maps shows that infection from the soil does not invariably occur.

There is some doubt about the question of the plant infecting the soil; although the weight of the evidence is in favour, it is not possible to prove it statistically because only three plots were sufficiently healthy to justify planting with diseased material. As shown in Table 7, all the plots which were healthy in 1943 became about 30 per cent. infected after planting with diseased setts, whereas there was less root-rot after diseased soil was planted with healthy setts. In plots 3 and 6 this was reflected in a reduced yield, but in plot 4 the yield actually increased. This increase might be due to the effect of cultivation, since plot 4 was previously under the "bush" treatment which may have depressed yield in 1943. The recovery, at least temporarily, of some infected plants when grown in disease-free soil, was established.

Conclusions

The pathogen remains in the soil, when an active outbreak of root-rot is rogued of all cocoyams.

Infected plants may recover when planted in diseased-free soil, but this recovery is often temporary and they may carry the disease with them.

Pot Experiments

The following experiments were carried out concurrently with the field trials, with the object of confirming or discrediting the conclusions suggested by the latter. Except where stated otherwise no precautions were taken to keep the plants free from insects, but they were grown at least 20 yards from any other cocoyams, and at least half a mile from the nearest known outbreak of root-rot.

1. Spread of Pathogen

Observations have shown that root-rot does not occur simultaneously over the whole area planted, but starts from a number of foci and spreads radially. This does not suggest the development of a toxin in the soil, but rather the spread of the pathogen. To investigate this point, soil was moved with as little disturbance of the profile as possible to nine pots, three of which were filled with soil from an uninfected area where cocoyams were growing vigorously, three with soil from a spot where cocoyams were suffering from root-rot, and three with soil from an adjacent spot where cocoyams were still healthy. In the field the disease soon spread to the area from which the third lot of soil was taken.

Healthy cocoyams, all from the same uninfected site, were planted one to each pot, and the pots arranged in three groups, each consisting of one pot of each treatment.

In the pots, root-rot developed only in the three pots filled with soil from the diseased spot. The disease did not appear in the pots filled with soil from the site to which the disease spread one month later.

TABLE 6

Monthly Distribution of Outbreaks on Experiment 4

Treatment	Plot No.	June	July	Aug.	Sept.	Oct.	Total
Diseased Soil, Healthy Setts.	2	2	17	3	—	—	22
	5	4	4	6	2	—	16
	7	11	9	—	1	—	21
Partly Diseased Soil, Healthy Setts	1	10	5	4	1	—	20
	8	1	18	—	1	—	20
Healthy Soil, Diseased Setts	3	2	11	1	1	—	15
	4	8	6	—	—	—	14
	6	1	5	4	1	—	11

TABLE 7

Comparison of Yields and Plot Area Infected on Experiments 3 and 4

Treatment in Experiment 4	Plot No.	Percentage Plot infected		Yield (Lbs.)	
		Area 1942-3	1943-4	1942-3	1943-4
Diseased Soil, Healthy Setts	2	96	91	32	19
	5	78	68	82	31
	7	83	89	46	23
Partly Diseased Soil, Healthy Setts	1	43	32	58	75
	8	21	17	56	45
Healthy Soil, Diseased Setts	3	0	27	129	46
	4	2	34	121	127
	6	2	31	73	46

$r=0.90$ ($P=0.01$, $r=0.83$)

Conclusion

This experiment proves that the disease is carried in the soil and indicates that the disease spreads not by a progressive change in the soil, such as the development of a toxin, but the dispersal of a pathogen.

2. Surface Sterilisation

The transmissibility of the disease through soil having been proved conclusively by earlier workers, and repeated by the writer in the previous experiment, it was necessary to show whether or not the disease could be carried also in the plant tissues.

Twenty cormels were collected from plants suffering from root-rot in the field experiments. All roots, both healthy and diseased were carefully removed, the cormels thoroughly washed in water and then divided into two equal lots. The ten cormels of lot A were treated by soaking in 2 per cent. formalin for 10 minutes, washed and planted two in each of 5 pots. Set B was planted similarly after washing, without formalin treatment. Controls consisted of five pots with two cormels each collected from healthy plants. All pots were filled with the same potting soil consisting of compost and top-soil from the area where cocoyams were growing without root-rot. All plants were kept in a greenhouse and sprayed weekly with nicotine solution.

Four months later the plants were lifted. The controls were healthy plants two feet tall with no signs of root-rot. Lots A and B were identical; the corms were alive, but with one exception, dormant and with no healthy roots. One cormel had sprouted and grown weakly, some roots showing characteristic lesions of root-rot, and others dead.

Conclusion

This experiment proves that the pathogen is either carried inside the cormels from an affected plant, suggesting systematic infection, or if superficial, is resistant to washing and formalin treatment.

3. Inoculation with Carborundum

This experiment was done to find out if the pathogen present in plant tissue can be transmitted by the usual virus technique, and if it is capable of causing root-rot under soil conditions where cocoyams are growing healthily.

Roots were taken from the diseased plants obtained in Pot Experiment 1. The rotten and discoloured parts were removed. The remaining apparently healthy tissues were washed in running water to remove all trace of soil. After an examination which failed to reveal any mycelium, these roots were kept overnight in distilled water.

Next morning, nine healthy cocoyam plants were selected from many growing in an area where no root-rot was present. The roots were exposed without damage by carefully removing the surface soil. The roots from the diseased plants were dried with filter papers, crushed in a pestle and mortar with fine-grain carborundum powder, and rubbed gently on the exposed roots of the healthy plants. The soil was replaced to cover the roots as before.

Four months later the plants, some of which had shown the wilting symptoms of the disease, were lifted. Four plants had healthy roots with no sign of root-rot, showing that the mechanical effect of the treatment had not been harmful. Five plants showed symptoms of the disease—poor root-system, lesions on the roots, and the remains of many rotten roots.

To confirm infection, these plants were grown in four pots, filled with soil in which cocoyams had grown for four months without root-rot. These pots were kept in a green house, the plants being sprayed weekly with nicotine solution. After four months the plants were lifted. All showed typical root-rot symptoms, one so severely affected that all roots were dead.

Conclusions

The pathogen responsible for root-rot was present in apparently healthy root tissues, and was transmitted by gently rubbing these tissues crushed with carborundum powder on the roots of healthy cocoyams growing under conditions where root-rot did not occur spontaneously.

4. Grafting Experiments

Three sets of three pots each were used :—

Set A contained healthy plants growing in uninfected soil.

Set B contained plants which had been infected through growing for one year in soil taken from a diseased area.

Set C as set A for control.

The pots of sets A and B were placed side by side in three pairs, and a petiole of the diseased plant in each pot cut to fit a slot cut in a petiole of the healthy plant. The two petioles of each pair were fitted together and bound with grafting tape.

Three months later the plants were lifted, washed and examined for symptoms. All plants in Set C were healthy ; all in Sets A and B showed severe root-rot.

The pots were replanted (leaving the soil undisturbed) with healthy plants from an uninfected area. Two months later all the plants in Set B were severely infected, all those in set A had some rotten roots but only one showed severe symptoms of root-rot. This suggests that the soil in which diseased plants had grown for a year contained a higher concentration of the pathogen than that in which plants had been infected for only three months, but it also contributes further evidence that previously uninfected soil can become infectious after diseased plants have grown in it.

Conclusion

This experiment indicates that the disease is transmissible through the aerial parts of the plant, and is not localised in the roots. Although no insects were observed on the plants during this experiment, no precautions were taken to exclude them, and transmission might have occurred through the contact of cut surfaces, or through insect vectors. The absence of the disease from the control plants in adjacent pots supports the former suggestion.

Resistance Trials

Wright (*loc. cit.*) showed that none of the varieties of *Xanthosoma* then available had any resistance to the disease. During 1937 and 1938 new introductions were made directly from Hawaii, Sierra Leone and Nigeria, and through the good offices of the United States Department of Agriculture and the Royal Botanical Gardens, Kew, from Trinidad, B.W.I., Puerto Rico and the Canal Zone.

Most of these new introductions succumbed to root-rot at Aburi, but eight varieties have been tested in resistance trials at Tafo since 1942. These varieties are :—

Xanthosoma violacceum var. Yautia Palma
,, sagittaefolium var. Blanca
,, ,, ,, Parrim
,, ,, ,, Conbiche (Deerhorn)
,, ,, ,, Morado
,, ,, ,, Otto Chino
,, ,, ,, Caracu Morqueta
,, ,, ,, Charaumae

Two rows (each of thirteen plants) of each variety were interplanted with rows of the local variety as checks, on land which previously carried Field Experiment 1 and was therefore known to be uniformly infected.

The variety *Xanthosoma violacceum* var. Yautia Palma proved to be very highly resistant, but unfortunately inedible. The varieties Conbiche and Morado are more tolerant than the local types, but not sufficiently to be of economic value.

Local Selection

Single plants of the local variety sometimes stand unaffected, while the rest in the farm succumb to the disease. On the assumption that bud-mutations are not uncommon in this species (since many varieties are known, although seed is rarely formed) thirty of these plants were propagated from cormels and planted in clonal rows in 1943. Alternate rows were, planted with unselected plants as checks and a source of infection.

After one season, the lowest infection rate in the check rows was 20 per cent. with a mode at 80 per cent. The lowest infection rate in the selections was, 10 per cent; the mode for all selections was 90 per cent. Two selection-rows, each with only two plants out of ten infected, were flanked by check rows showing between 40 and 100 per cent. infection. This is a better performance than that of any introduced edible variety, indicating potentialities of selection among local types.

Seed Production

When grown under light shade (provided by *Leucaena glauca*) the local cocoyam flowered freely. All spathes were watched, and none set seed. A considerable amount of hand-pollination, both self and cross, was done without success. None of the introduced types flowered.

Discussion

Consideration of these results leads me to the conclusion that probably two factors are responsible for the full expression of root-rot symptoms.

One of these is usually, but not invariably, present in soil in which cocoyams can grow without signs of the disease; the factor is probably one or more weak parasites, fungal, bacterial or nematode, and is rare in garden soil or compost.

The second factor is a primary pathogen which seems to have virus-like properties. In its capacity to remain in the soil and infect plants from it, this agent resembles the virus of Tobacco Mosaic and Tobacco Necrosis. There is some evidence that this agent becomes systemic in the cocoyam plant and the fact that recovery may or may not occur after transplanting to uninfected soil indicates the existence of the contributory soil parasite.

The spread of the disease through the country and in the individual farm is attributed to this virus-like agent. The ease with which it is carried in soil makes inevitable considerable dispersal during cultural operations, on tools and feet. The rapidity of the spread suggests that other methods exist, and in this connection it is significant that the aphid vector of the Bunchy-top virus of Bananas, †*Pentalonia nigronervosa Coq.*, has been found on cocoyams during the active spread of all outbreaks in which a search was made. (This aphid is easily overlooked as it feeds on the base of the petiole inside the crown). The history of Bunchy-top disease given by Wardlaw (5) reveals an emphasis on soil fungi as a cause of the rotting of roots, by early investigators, and this disease seems not unlike cocoyam root-rot in some respects.

The two most critical investigations still to be done are (*a*) the relationship of this insect to the disease and (*b*) the effect of sterilised and unsterilised soil on "virus" infected plants, in order to determine the relative importance of the two factors believed necessary for the full expression of root-rot symptoms.

† Determined by the Imperial Institute of Entomology, British Museum.

Summary

A series of *Field Experiments* have confirmed the results of earlier investigations and produced evidence that :—

1. Ordinary cultural methods do not reduce the incidence of root-rot.
2. Rogueing of all "wild" cocoyams immediately after clearing the "bush," and then replanting with healthy "setts," delays the disease so that one crop may be obtained.
3. A satisfactory yield of cocoyams may be obtained by controlling "bush" shade without clearing or disturbing the soil.
4. Cocoyams in "bush" are not immune to this disease.
5. Once infected, plants may carry the disease and infect the soil. Sometimes they recovor when planted in uninfected soil. This recovery may be temporary.

Pot Experiments have given evidence that :—

6. The spread of the disease is not due to a progressive change in the soil, such as the develpment *in situ* of a toxin.
7. The disease may be carried by corms which have been surface-sterilised and all roots removed.
8. The disease may be transmitted by gently rubbing an extract of apparently healthy roots from diseased plants with carborundum powder on the roots of healthy plants.
9. The disease may be transmissible through leaf petioles "grafted" together.

Resistance trails have shown that of the varieties tried, only *Xanthosoma violacceum* var. Yautia Palma is resistant, but that further individual plant selection among local varieties has possibilities.

It is suggested that a useful working hypothesis for further investigations is provided by considering the primary pathogen to be a virus, which may alone cause lesions on the roots and render the plant susceptible to a variety of weak parasites often present in the soil.

Acknowledgments

It gives me pleasure to acknowledge the advice and assistance given by Mr. J. Obeng throughout this investigation. I am grateful to Mr. S. H. Crowdy for supervising the 1943-4 Field Experiments during my absence.

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PLANT BREEDING IN RELATION TO HUMAN NUTRITION (1)

BY

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A prominent economist (2) has stated recently that after ten years in which to reorganize its agriculture and to readjust its consumption, this nation could feed twice its present population at a higher level of health and of working efficiency under present conditions. Here is a challenging statement to all agriculturists, regardless of whether they consider the establishment of such a goal as feasible or, perhaps, in one of its implications, even desirable. There can be no serious dissent from the idea of maintaining a level of human nutrition that assures health and working efficiency, but for the continued development of a higher order of civilization it is not unlikely that population should level off at a place well below the complete utilization for food of all that could be produced efficiently.

All available evidence indicates that man lived for a few million years as a savage when practically all his energies, aside from those required from time to time in fighting enemies, were expended in acquiring food and shelter. These he took more or less as nature had provided them or as he could prepare them by primitive means ready at hand. From this plane of existence there emerged and developed an agricultural type of civilization. During several thousand years man learned to grow crops and domesticate animals to satisfy his wants but, owing to lack of agricultural knowledge, dependence on hand tools or crude implements, the surplus production was never very great. Partly because of this and partly because of poor transportation facilities large segments of mankind were periodically subjected to famines with all their disastrous consequences. It is only in the last two hundred years that man has acquired the agricultural knowledge and developed the machinery necessary to grow and process the vast surpluses which we in the United States are at present capable of producing.

We associate this modern era with the most remarkable and rapid progress known to man. We take for granted and accept the modern fruits of agriculture and industry, not always realizing that they could not have been developed except for an earlier and contemporaneous development of the physical and biological sciences. Of even greater importance to this and succeeding generations is the fact that continued and further progress is only possible with further scientific knowledge.

When man reached that stage in his agricultural development where not all his energy was required to produce the necessities of life, he began to have more time for thinking and theorizing and later for experimenting to determine the truthfulness of his theorizing. It was in such an environment that the sciences were developed. We should see to it that man never again is compelled to revert to the state of expending all or even the greater part of his energies in merely providing the essential necessities of life. For fear of being misunderstood let me emphasize that this is not necessarily a plea for more leisure, indispensable as that is for health and happiness. It is a plea for work of a kind that assures continued progress in man's struggle for a higher plane of living.

It is hardly necessary to mention to a generation that has experienced two disastrous world wars that social progress has not been all that could be desired. We are not particularly concerned with this problem here except to point out that social progress must go hand in hand with progress in other lines of human endeavour. In fact, if this does not happen we will probably continue trying to settle our differences by wars, each more terrible than its predecessor. I am inclined to agree with E. Parmalee Prentics (3) in his contention that the acquisition of adequate food has been one of mankind's strongest motivating influences in determining his social evolution. Periods of population pressure and consequent sharpened wants without ready means of gratification are associated with discontent, upheavals and tyranny. Two remedies suggest themselves: Reduction of population pressure and production of more food at relatively low cost. The former is not under consideration at the moment except to note that, unless a solution is eventually found to this phase of the problem, we are likely to find ourselves in a "vicious circle", for certainly there is a limit to the quantity and quality of food that may be produced.

What is the plant breeder's possible rôle in this world dream? He can help meet the food challenge by breeding more productive and more nutritious plants for direct or indirect consumption by man. I shall discuss the question by citing some objectives that already have been attained by breeding and by pointing out some possibilities for the future.

Some Accomplishments of the Plant Breeder

The plant breeder, in common with most other agricultural scientists, has devoted his major efforts towards increasing production at lower cost. While he has not neglected quality

(1) Address of the vice-president and chairman of the Section on Agriculture (O) of the American Association for the Advancement of Science, Cleveland, Ohio, September, 1944.

(2) Jno. D. Black, "Food Enough". The Jaques Cattell Press, 1943.

(3) E. Parmalee Prentics "Food, War and the Future". Harper and Bros, 1944.

particularly in its more general aspects, the breeding of plants to enhance specific nutritive values for man is a relatively new venture and one that has not as yet received a great deal of attention.

Dr. M. A. McCall (4), of the United States Department of Agriculture, has summarized recently some of the increased yields that have resulted from plant breeding. It is estimated that the increased yield from hybrid corn grown in the United States in 1943 was 669,480,000 bushels or the equivalent to 7,364,280,000 pounds of pork, enough to supply each man, woman and child in the nation with 54 pounds. The new varieties of oats resistant to smut and rust, Vicland, Cedar, Tama, Vikota, Control and Marion, will probably increase average yields at least 7.5 bushels per acre. Based on the estimated acreage occupied during the present year these varieties will result in an increased production of 75,000,000 bushels of valuable feed, or, if consumed directly by man as oatmeal, the equivalent of seven servings for each of the something over two billion persons in the world. Thatcher, a hard red spring wheat released in 1934, rapidly replaced the then existent varieties because of its resistance to stem rust. Unfortunately, Thatcher in common with other commercial varieties grown at that time was susceptible to leaf rust and as a consequence was damaged to some extent during years when this disease was present. In the meantime other new varieties, such as Regent, Rival and Pilot, that were resistant to leaf rust as well as stem rust, had been bred. It is estimated that in 1942 when stem rust was present the growing of resistant varieties resulted in the production of 100,000,000 additional bushels of hard red spring wheat in the states of Minnesota, North Dakota and South Dakota. I am advised by Dr. H. K. Hayes, of the Minnesota Agricultural Experiment Station that promising varieties released for distribution in 1944 include Newthatch from Minnesota and Midas from North Dakota.

The growing of disease resistant varieties not only increases average production but provides crop insurance. For example, in 1935 when stem rust was prevalent, Thatcher wheat on 31 farms located in 16 counties of Minnesota (5) yielded on the average 27.3 bushels per acre compared with 6.5 bushels for Marquis grown in the same field. To the individual farmer the growing of resistant or susceptible varieties in epidemic years may mean the difference between success and economic disaster. Many other equally impressive examples of increased production of food or feed brought about by the efforts of plant breeders might be mentioned not only among field crops but vegetable and fruit crops as well. Likewise, a lengthy discussion would be required to present the marked advances that have been made in breeding plants for fibre, oil and other uses, but let us turn now to a brief consideration of accomplishments more in line with enhancement of nutritional values of direct use to man.

About fifteen years ago a close physiological association between yellow endosperm and provitamin A was found by the Indiana Agricultural Experiment Station (6) among the segregates from a cross between Reid Yellow Dent and Johnson County White corn. Shortly thereafter the Texas Station (7) demonstrated a quantitative relation between the inheritance of yellow endosperm and provitamin A in dent corn. Since endosperm is triploid, monohybrid inheritance for the dominant yellow colour would lead to the following factorial compositions: YYY, YYy, Yyy and yyy. The triple recessive would, of course, be white. It was shown that the endosperms with these genotypes carried on the average 7.5, 5.0, 2.25 and 0.05 units of provitamin A per gram, respectively. It is probable that similar relations exist among yellow and white sweet corns.

The Louisiana Agricultural Experiment Station in co-operation with the U.S. Department of Agriculture has shown that sweet potatoes may be bred for a higher carotene content. Among the F_1 seedlings from crosses between heterozygous parents, selections were made that far exceeded either of the parents in micrograms of carotene per gram of sample. This investigation, together with others that have been reported, indicate that varieties of sweet potatoes may be developed with distinctly higher nutritive values than those now in commercial production.

The U.S. Southeastern Regional Vegetable Breeding Laboratory is actively engaged in breeding certain vegetables for higher ascorbic acid (Vitamin C) content. Dr. B. L. Wade, in charge of the Laboratory, has recently informed me that there have been released for general distribution two varieties of cabbage with distinctly higher ascorbic acid content than any commercial varieties now grown in the area. In co-operation with the Florida Agricultural Experiment Station, a variety of snap beans has been developed which possesses, in addition to hardiness and disease resistance, an ascorbic acid content as high if not higher than competing commercial varieties.

Poole, Grimball and Kanapaux (8) have obtained results which show that hereditary factors are more important than season or location in producing ascorbic acid differences among 25 lines of cabbage. Season to season differences were significant in six lines, but in only one was the ascorbic acid content greater in the fall than

(4) M. A. McCall, "Crop Improvement, a Weapon of War and an Instrument of Peace", an address presented at the annual meeting of the American Society of Agronomy, 1943.

(5) H. K. Hayes, E. R. Ausemus, E. C. Stakman, C. H. Bailey, H. K. Wilson, R. H. Bamberg, M. C. Markley, R. F. Crim, M. N. Levine, *Minn. Agr. Expt. Sta. Bull.* 325, 1936.

(6) S. M. Hauge and J. F. Trost, *Jour. Biol. Chem.*, 86: 167-172, 1930.

(7) P. C. Mangelsdord and G. S. Fraps, *Science*, 73: 241-242, 1931.

(8) Chas. F. Poole, Paul C. Grimball and Margaret S. Kanapaux, *Jour. of Agr. Res.* 68: 325-329, 1944.

in the spring. A negative correlation was reported between ascorbic acid concentration and head weight. Wade, Heinze, Kanapaux and Gaetjens (9) have found in certain snap bean crosses transgressive segregation for ascorbic acid content, indicating that two or more complementary hereditary factors are operating to determine ascorbic acid content in this vegetable and that the chances are good for synthesizing a new variety distinctly superior with respect to this substance.

These few examples will serve to show that the plant breeder has already made a beginning in increasing the vitamin content of plant parts used directly for human food. It is, however, just a beginning in a field of activity that should be productive of gratifying results.

Substantial progress has been made in selecting and breeding plants for quality, flavour, sugar content and other characteristics that make the plants more desirable as human food when it was known what was desired by the consuming public. This statement is particularly true if one considers the prodigious effort of both the known and unknown plant breeders that has gone into creating the many highly acceptable vegetables, fruits and nuts we possess to-day. Selections made by early man, though they may have been made more or less unconsciously, were undoubtedly an important determinative factor, but rapid progress was not made until the importance of inheritance was appreciated. A mere listing of accomplishments in this general field would fill pages. There are practically no vegetable, fruit or nut crops in common use to-day that have not been improved in quality, flavour or some other important characteristic by plant breeding. It may be profitable now to consider some possible future activities.

Possible Future Objectives of the Plant Breeder

The plant breeder who is attempting to improve the nutritive value of plants for man is oriented in his efforts by developments in the field of nutrition. We know enough about plants to assert with confidence that every plant character, whether it be morphological or physiological, is conditioned in its expression by two sets of forces, environmental and hereditary. Effective progress of the breeder will depend upon the range of hereditary variation in the plant material. As the nutritionist learns more and more about the plant substances essential to the nutrition of man, the breeder may correspondingly focus his attention on the more important substances and particularly those that show a wide range of hereditary variation.

As has been pointed out already, some progress has been made in breeding plants for increased vitamin content, but this field of endeavour has barely been opened and prospects for the future appear promising indeed. Newman (10) reported consistent differences in thiamin (B_1) content between varieties of spring wheat grown at different locations in the prairie provinces of western Canada. Similar differences have been found between varieties of winter wheat grown in the Great Plains of the United States. These facts suggest that it would be entirely feasible to produce by breeding a wheat with a higher B_1 content than any now commonly grown. Moreover, it may even be possible to change by breeding the relative thiamin content of different parts of the wheat kernel separated in milling. If this could be done it might prove of importance, as present milling processes and the preference of the consuming public for white bread make it difficult to recover the desired amount of B_1 in the flour. Making up this deficiency by "enriching" the flour is now quite generally practised, but I understand there are some experts in human nutrition who believe that until we know more about the specific functions of the vitamins and their interrelations, it is preferable to "enrich" by natural rather than by artificial means. Be that as it may, when one considers the importance of wheat flour in the human diet, it behoves plant scientists, millers and nutritionists all working together to make this product as wholesome as is possible.

Adams and Smith (11) have recently summarized results that have been obtained at various agricultural experiment stations in studying varietal differences of fruits and vegetables with respect to vitamin content. The Maine Station has shown that onions varied widely with respect to ascorbic acid content, depending on variety. Similarly, workers of the North Carolina Station and the U.S. Department of Agriculture have demonstrated differences with respect to this substance among varieties of blue berries, blackberries, dewberries, raspberries and muscadine grapes. Varieties of peaches may be a poor or good source of carotene (provitamin A), according to the Arkansas Station. Seventeen varieties ranged from 20 to 500 micrograms of carotene per 100 grams of peach or the equivalent of 33 to 833 International Units. Both the carotene and ascorbic acid contents of avocados vary widely, as shown by studies in Florida. These few examples of varietal differences are undoubtedly typical of many that may be found among other fruits and vegetables. While it is true that environment, stage of growth storage, processing and other factors are all important in determining the vitamin content of plant parts at the time they are consumed by man, the existence of significant hereditary differences with respect to these essential substances is all the assurance the trained plant breeder needs in order to proceed with confidence in his ability to produce new forms superior with respect to vitamin content. *However, this is probably not sufficient*

(9) B. L. Wade, P. H. Heinze, M. S. Kanapaux and C. F. Gaetjens, 'Inheritance of Ascorbic Acid Content of Snap Beans', In Press. *Jour. Agr. Res.*

(10) T. H. Newman, *Jour. Am. Soc. Agron.*, 109-116, 1942.

(11) Georgian Adams and Sybil L. Smith, *U.S.D.A. Misc. Pub.* 536, 1944.

justification to launch an extensive breeding programme. The breeder should have the assurance of the nutritionist that an important nutritional need will be met if the proposed breeding programme is successful. I think it is fairly obvious that the nutritionist and the plant breeder must work together if the latter's efforts are to be most effective in raising nutritional levels for man.

In considering possibilities for enhancing vitamin content of plants by breeding, the lower forms such as algae and yeast should not be overlooked. In a recent report by Spoehr (12) it is pointed out that because of the rapidity of growth of certain algae supplied with air, light and simple mineral nutrients, they may become an important source of vitamins. Species of algae were found to vary greatly with respect to carotene content. Yeast may become a more important source of B Vitamins as well as protein for human food. Burkholder (13) has estimated that the breweries of America could supply annually about 200 million pounds of yeast, half of the dry matter being nutritious protein. This estimate is based on an output of 65 million barrels of beer and on the assumption that the brewers fully utilize their yeast by-product. In connection with a study of some 200 kinds of yeast with respect to their production of vitamin B_2 Burkholder reported a strain isolated from sour milk that was particularly efficient in the production of riboflavin. Here is a fascinating field for the breeder of the lower plant forms.

Taking up next the mineral constituents in human food we find that in recent years significant advances in our knowledge have been made. Early nutritionists placed major emphasis on proteins, carbohydrates and fats with some attention to water and minerals. Later vitamins came into prominence. As a result of numerous studies in recent years, minerals are now recognized as essential factors in most if not all metabolic processes taking place in the body. The ash of the body is composed primarily of calcium, magnesium, sodium, potassium, phosphorus, sulfur and chlorine. The trace elements known to be essential to animal life are iron, copper, iodine, manganese, cobalt and zinc. With the exception of sodium, chlorine, iodine and cobalt, plants require these same elements and in addition boron. The significance of other trace elements found in the ash of plants is not understood at present. It is known that certain elements, such as selenium, arsenic, lead and fluorine, may be definitely poisonous in relatively low concentrations to both plants and animals. Since practically all man's food except fish and common salt must come directly or indirectly from land plants, the importance of the soil-plant relation becomes obvious. One of the Federal Bankhead-Jones Regional Laboratories is concentrating on a study of the three-way relation between soil, plant and nutrition.

It is well known that the mineral and other constituents of plants reflect within biological limits the mineral and other constituents of the soil on which they grow. The mineral deficiency diseases of animals in certain areas are good examples of how serious may be the consequences of a deficiency in the soil. It is also well known that different species of plants growing under similar conditions may vary widely with respect to their mineral contents, although less is known regarding variation between strains and varieties. Dr. R. R. Robinson, working at the U.S. Regional Pasture Research Laboratory, found significant and consistent differences with respect to calcium and phosphorus in clones of white clover when grown on different soils. It is reasonable to expect that hereditary differences exist among plants in mineral assimilation just as in other respects.

The plant breeder undoubtedly could produce strains of plants that would be relatively efficient in extracting certain elements from the soil, and such strains might be useful at least temporarily in controlling some deficiency diseases. It should be recognized, however, that regardless of the success of plant breeding efforts in this direction, eventually, depleted or missing elements in the soil must be supplied by artificial means. On the other hand, the plant breeder is probably on more stable ground to breed for the enhancement of those plant constituents which for their development draw largely on elements that are normally present in abundance such as nitrogen, carbon, oxygen and hydrogen. In this category of plant constituents occur proteins, carbohydrates and fats. Much has already been accomplished along this line, but there is still much to do. As soon as more is learned regarding the function and relative importance of the various fractions of these three food essentials in the diet of man, the breeder will be in a position to select plants for the desired characteristic.

Another approach to improving dietary values both with respect to quantity and quality is by breeding for better animals or better animal products to be consumed by man. Marked progress has already been made, as is evident from the better types of meat, dairy and egg producing animals that have been bred, but much still remains to be done. To point out but one line of work that promises a bright future, breeding for disease resistance may be mentioned. The control or elimination of bovine mastitis would increase greatly milk production or the subjugation of avian leukosis would add enormously to egg production. Breeding may never completely control such diseases, but certainly such an attack would be helpful in solving the problem. Some recent results from swine breeding would appear to justify a further application in animal breeding of methods so successfully used by plant breeders,

(12) H. H. Spoehr, "Annual Report of the Chairman of the Division of Plant Biology" (Reprinted from Carnegie Institution of Washington Year Book, 42, 1943).

(13) Paul R. Burkholder, *The Yale Scientific Magazine*, 18: No. 1, October, 1943.

namely, inbreeding as a means of selection followed by the incorporation of hybrid vigour in the commercial variety. It is not within the scope of this paper to discuss animal breeding, but I think it is fairly obvious, as in the case of plant breeding, that work in this field may be expected to continue to make substantial contributions to raising the nutritional level of mankind.

Just as plants, within certain biological limits, reflect the nature of soils on which they grow so, likewise, animal products reflect to some extent the composition of plants on which the animals feed. This suggests still another approach for the plant breeder, namely, to improve crops from the standpoint of animal nutrition. Forage crop breeding, although recently developed, seems to offer unusual opportunities. Not only is it important to obtain greater yields and yields more uniformly distributed throughout the growing season, but it is likewise important to obtain forage of such a composition as to be highly nutritious to grazing animals and therefore of indirect benefit to man. The most economic feed for cattle, sheep and other farm animals is pasture. To provide adequate nutritious herbage throughout the grazing season is the aim of the breeder working with pasture plants. Breeding for some qualitative characteristics in forage crops will have to await the further development of information regarding the nutritional requirements of man and of the animals that help to sustain him.

Conclusion

To conclude, the plant breeder has a very definite responsibility in helping to place man on a higher nutritional plane and hence to help make him a more effective and contented member of society. I like to think of the problem from this angle rather than from the standpoint of producing more food just to feed more people. Plant breeders collectively have played an important rôle in bringing about the high agricultural production of which we are capable at present. Only a beginning has been made in improving the nutritional qualities of food by plant breeding, but results already obtained indicate a promising future for this field of activity. The nutritional values of various plant constituents are guideposts for the plant breeder and in many instances information is incomplete. He can probably accomplish most by seeking to enhance those plant constituents of a high nutritive value that are largely dependent for their development on elements abundantly present in the plant's environment. A natural corollary is to breed plants for a reduction of constituents that inhibit nutritional value. In the long run the problem of mineral deficiencies in the soil can probably best be solved either by adding the deficient element to the soil or directly to the diet. The breeder already possesses the techniques and methodologies to enhance heritable nutritional factors in plants once those factors have been clearly identified. However, in order to proceed with confidence in the value of the final outcome of his endeavours in this direction he should have the constant guidance and counsel of the nutritionist. They working together must answer the significant question, What will be the real value of enhancing this or that component of the aggregate that constitutes the human diet?

Reprinted from *Science*, New Series, Vol. 101, No. 2621 pp. 288-293, 1945.

CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Bananas and Minerals

In the language of agricultural chemistry the term "minerals" is sometimes used as a kind of slang when artificial fertilizers are meant. We do not propose to defend the appropriateness or historical justification of that sense of the word, but to give a brief review of the first public report of a series of experiments made for the purpose of controlling the Panama disease of bananas. When bananas were first introduced into Central America they grew so easily that boom towns founded on the banana industry sprang up, too. About 1910 a fungal wilt—the so-called Panama disease—suddenly made its appearance. Spreading unequally but on the whole rapidly, it completely destroyed many plantations; towns became derelict, and the plantations "went on the march" from the coast to the interior in search of uninfected soil. This shifting cultivation served for a time, but by 1920 the disease had become a major problem. About the year 1922, B. T. Galloway of the U. S. Department of Agriculture, suggested applying the new technique of pH determination to banana soils, and Lewis Knudson of Cornell University found that the extent of damage increased with acidity. This led to the retention of the services of soil chemists by the two big American companies concerned in the Caribbean banana trade. One of these men, Dr. George D. Scarseth, has recently released the details from which this note has been made.

Mycologists were also at work and a great deal of information about the wilt fungus was obtained. The association of the disease with acid soils became the basis for extensive and systematic exploration to find areas of alkaline or neutral soils, and the fact that the acid soils were often sandy or open in texture led to the formulation of a theory connecting aeration and incidence of the disease. Experiments on the use of lime and fertilizers, begun in 1932 in Honduras, suggested that the problem was more intimately connected with minerals than had been supposed. Simply to supply lime to correct the acidity was not enough; it seemed necessary for a period of

several years to elapse after diseased plants had been removed before a healthy banana crop could be established. Light soils in the humid tropics are acid because lime and other materials are readily washed out from them. A considerable proportion of clay must be present, in order that the colloidal true minerals of the soil may help to retain whatever is added by man. The fungus, however, was not greatly affected by the addition of inorganic plant nutrients. What has been called "biological disinfection" was practised to oxidize the fungus away. This is similar in principle to what has been found necessary in England to avoid damage from a fungal disease of cereals. It depends upon the incorporation of organic matter into the soil, in conjunction with artificial fertilizers. In the banana plantations several successive catch-crops of herbaceous plants were grown and ploughed into the soil. The decay of the materials through the action of bacteria and other microbes practically swamped the noxious fungus, which was unable to withstand the intensive competition set up. Leguminous plants were best for ploughing-in, since they had a high ratio of nitrogen to carbon; this ensured that their decomposition was rapid and energetic, and thereby most of the rather specialized Panama disease organisms were decomposed, too. We think that chemists have reason to be proud of this conquest of disease.—(*Chemistry and Industry*, No. 19, p. 145, 1945.)

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Carotene and Sugar Content of Carrots

The nutritional value of carrot roots is due largely to their contents of carotene and sugar, and both these constituents are most abundant in the phloem. It is of interest to note, therefore (1), that although the phloem constitutes more than 60 per cent. of the root the proportion is greatest in young roots, although carotene content increases with maturity but is least in 'large strain' carrots (2). Carotene content is influenced by manuring, but carotene losses during storage are negligible until the stored roots sprout in the spring. Although sugar content is often a good index of 'quality', the correlation between desirable taste and refractive index of the juice is often upset by the presence of an unidentified bitter constituent (3).

Maintenance of high quality (that is, high sugar stocks) may be difficult, as these roots when replanted for seed production often rot and so fail to produce a satisfactory crop of seed (4). Seed production, too, may be complicated by the temperature requirements of the carrot (5), H. S. Sakr and H. C. Thompson reporting that the initiation of flower primordia is inhibited at temperatures in excess of 70°F. although doubtless the critical inhibiting temperature is influenced by the previous history of the carrot.

Not less important than the taste and sugar content is the shape of the roots, and traditionally carrots are grown on land "manured for a previous crop", fresh animal manure being thought to induce branching or forking of the roots. G. J. Raleigh (6) reports, however, that with carrots in sand culture supplied with a complete nutrient solution, the addition of cow manure free from urine did not increase the amount of root branching, but cow or horse urine did cause forking. Attempting to discover what substances were responsible for this effect, Raleigh found that urea, ammonium hydroxide and ammonium carbonate all induced root branching, but a variety of growth-substances tried were without effect.

(1) Werner, H. O., *Proc. Amer. Soc. Hort. Sci.*, 38, 267 (1941).
(2) Pepkowitz, L. P., Larson, R. E., Gardner, J., and Owens, G., *Proc. Amer. Soc. Hort. Sci.*, 44, 468 (1944).
(3) Brown, H. D., Miller, M. K., Alban, K., Schulkers, R., and Murmane, C., *Proc. Amer. Soc. Hort., Sci.*, 44, 465 (1944).
(4) Ellis, M. K., *Proc. Amer. Soc. Hort. Sci.*, 40, 536 (1942).
(5) Sakr, H. S., and Thompson, H. C., *Proc. Amer. Soc. Hort. Sci.*, 41, 343 (1942).
(6) Raleigh, G. J., *Proc. Amer. Soc. Hort. Sci.*, 41, 347 (1942).
(*Nature*, Vol. 155, No. 3942, pp. 613-14, 1945).

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Toxic Spray Substances and Plant Growth

One result of the continued use of sprays containing toxic inorganic constituents may be the accumulation in the soil of substances deleterious to plant growth. Of practical interest, therefore, are experiments described by N. F. Childers (1), who found that the presence of sodium arsenate in the soil had a stimulating effect on 'Delicious' apple seedlings when the concentration was not more than 20 parts per million. Between 60 and 160 parts per million, toxic effects were apparent, and if the concentration was more than 100 parts per million the seedlings died. Equivalent amounts of arsenic in the form of lead arsenate were less toxic, and lead chloride even at 160 parts per million exerted no deleterious effect. More carefully controlled experiments with plants in gravel culture showed that 20 parts of arsenic per million of culture solution stimulated the growth of apples and of rye but depressed the growth of grapes. Both apples and grapes were tolerant of 200 parts of lead per million of solution and both showed a progressive decrease in growth as the copper content of the solution rose from 10 to 30 parts per million.

Different fruits show differing tolerance of arsenic, but R. C. Linder (2) reports that peaches are especially susceptible, and if the arsenic content of the leaves exceeds 2 parts per million of dry matter, marginal and interveinal burning and shot-holing of the leaves occur, with, in severe cases, defoliation. Apricots show a similar effect, but plums, pears and apples are more resistant, and plum foliage containing as much as 13 parts of arsenic per million of dry matter appeared healthy.

1. *Proc. Amer. Soc. Hort. Sci.*, 38, 157 (1941).
2. *Proc. Amer. Soc. Hort. Sci.*, 42, 275 (1943).
(*Nature*, Vol. 155, No. 3939, p. 523, 1945.)